




Research Article

Active restoration of post-mining forest benefits the activity density, but not the diversity of spider communities across the seasons in Ghana

Harriet Kinga¹, Frederick Gyasi Dampney² Danilo Harms³, Rudy Jocqué⁴, Arnaud Henrard⁴, Klaus Birkhofer¹

¹ Department of Ecology, Brandenburg University of Technology Cottbus-Senftenberg (BTU), Cottbus, Germany

² Forest Aid Ghana, P.O. Box KN 6218, Kaneshie-Accra, Ghana

³ Museum of Nature Hamburg - Zoology, Leibniz Institute for the Analysis of Biodiversity Change (LIB), Hamburg, Germany

⁴ Royal Museum of Central Africa, Tervuren, Belgium

Corresponding author: Harriet Kinga (harrietkinga@gmail.com)



This article is part of:

Gedenkschrift for Prof. Stefan H. Foord

Edited by Galina Azarkina, Ansie Dippenaar-Schoeman, Charles Haddad, Robin Lyle, John Midgley, Caswell Munyai

Academic editor: John Midgley

Received: 5 October 2024

Accepted: 21 November 2024

Published: 10 January 2025

ZooBank: <https://zoobank.org/7B641FB8-8150-47ED-A289-DA5DBE5EB563>

Citation: Kinga H, Dampney FG, Harms D, Jocqué R, Henrard A, Birkhofer K (2025) Active restoration of post-mining forest benefits the activity density, but not the diversity of spider communities across the seasons in Ghana. *African Invertebrates* 66(1): 1–18. <https://doi.org/10.3897/AfrInvertebr.66.138662>

Abstract

Forest restoration often involves monitoring programmes to determine whether biodiversity levels and ecosystem services have changed over time. This study investigated changes in ground-hunting spider communities (families Ctenidae, Lycosidae and Zodaridae) in an actively restored forest, an unrestored gravel mine, and two alternative land-use types (agroforestry system and an arable field) to assess whether a two-decade post-mine restoration programme has been successful in restoring biodiversity to levels of a reference natural forest. The overall activity density of ground-hunting spiders (based on both juveniles and adult specimens) was highest in the natural and the restored forest in the dry season and lowest in the arable field and agroforestry system in the wet season. The inverse Simpson index was highest at the gravel site in the wet season, followed by natural forest in both seasons and lower values in the restored forest. The community composition of spiders differed significantly between land-use types (open versus forest habitats) and the interaction between land use and season also differed significantly. The species *Pardosa injucunda* and *Trochosa gentilis* dominated the communities in the restored forest, but *Africactenus monitor* dominated the natural forest and *Hogna gratiosa* dominated communities in the gravel site. Surprisingly, active forest restoration promoted the activity density of ground-hunting spiders displaced by mining activities to levels even higher than in the reference natural forest after two decades. However, the community composition of the restored forest was more similar to the agroforestry system than to the natural forest. These results highlight the benefits of restoring former mining sites but also show the trade-offs in terms of restoration goals, as natural forest biodiversity of spiders was not achieved after 20 years.

Key words: Agroforestry system, Araneae, biodiversity conservation, community composition, deforestation, mining

Copyright: © Harriet Kinga et al.

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International – CC BY 4.0).

Introduction

Global deforestation rates continue unabated, with the majority of deforestation occurring in tropical regions that are home to primary forests and rich in biodiversity (Ritchie et al. 2021). According to the Global Forest Resource Assessment, the world has lost approximately 420 million hectares of forest since 1990 (FAO and UNEP 2020). In Ghana, deforestation rates are particularly high, estimated at 3.5 percent of the total forest area per year, equivalent to 315,000 hectares (World Bank 2020). Agricultural land use, logging, mining, and infrastructure development are the main drivers of deforestation, often leading to ecological imbalances with significant biodiversity and societal impacts in Ghana (Dampney et al. 2021; Abugre and Sackey 2022; Asare et al. 2022; Bentsi-Enchill et al. 2022) and worldwide (Hansen et al. 2010; Foord et al. 2020; Fitzgerald et al. 2021; Masolele et al. 2024). Several local and international initiatives have been introduced to address forest loss in Ghana including reforestation and sustainable land management practices, which aim to reduce forest degradation while restoring degraded ecosystems to support biodiversity and society (Dampney et al. 2021; Kumi et al. 2024). Both passive (unassisted) and active restoration programmes, such as planting tree seedlings, focus on restoring biodiversity while also providing ecosystem goods and services to local human communities (Dampney et al. 2020). Effective monitoring of restoration programmes is an important tool for evaluating outcomes and adjusting or revising restoration strategies, to achieve long-term conservation goals (Hansen et al. 2010; Bullock et al. 2011).

Historically, restoration monitoring in Ghana has often focused on the use of a few indicators such as tree species composition and diversity (Nero 2021) or soil attributes (Dampney et al. 2020; Brown et al. 2024), with little focus on arthropod biodiversity and their important contributions to ecosystem functioning (Birkhofer et al. 2024; Cardoso et al. 2024). The few studies to date that have included arthropods in their forest restoration monitoring programmes in West Africa have focused on higher taxonomic levels (e.g., order or family classification: Kyeremanten et al. 2020; Dampney et al. 2023). Taxonomic surrogacy addresses time and resource limitations and is often sufficient in ecological research due to comparable habitat requirements of species within families or genera (taxonomic sufficiency: Birkhofer et al. 2012). However, results from such approaches may still suffer from the lack of species-level identification, as species within a higher taxonomic group often have different ecological traits and may therefore respond differently to changes in habitat conditions (Ong and Hamid 2022). For a holistic view of the performance of restored ecosystems in terms of arthropod biodiversity recovery, the use of species levels in ecological monitoring programmes is therefore beneficial.

Here, we focus on spiders (Arachnida, Araneae) and their potential role as indicators of restoration success. Spiders are the dominant predators in terrestrial arthropod food webs (Potapov et al. 2022) and provide essential ecosystem services including provisioning (e.g., providing venom for the pharmaceutical industry), regulating (pest control and invasive species management; Dippenaar-Schoeman et al. 2005), supporting (nutrient cycling), and cultural and spiritual (e.g., providing a sense of place) services (Cardoso et al. 2024).

Changes in spider populations can also indicate shifts in insect populations, which are essential for ecosystem functioning (Marc et al. 1999). Spiders are an important food source for a variety of other organisms, including birds, small mammals and other arthropods, contributing to the overall biodiversity of the ecosystem (Marc et al. 1999). They also serve as bio-indicators for ecological monitoring due to their sensitivity to environmental changes caused, for example, by pollution, habitat modification or climate change (Jocqué et al. 2005; Nyffeler and Birkhofer 2017).

Among spiders, some taxa are known to be restricted to more open habitats such as Lycosidae Sundevall, 1833 (Jocqué and Alderweireldt 2006; Juakaly and Jocqué 2021) while others, such as some Ctenidae Keyserling, 1877 (Steyn et al. 2003; Jocqué et al. 2005; Henrard and Jocqué 2017) and the Zodariidae Thorell, 1881 (Jocqué 1993; Nzigidahera et al. 2011; Dankittipakul et al. 2012), are characteristic of tropical forests. These taxonomic groups are therefore ideal for studying the impact of deforestation and monitoring habitat restoration. We therefore studied ground-hunting spider communities of the families Ctenidae, Lycosidae, and Zodariidae in an unrestored and restored gravel mine site 20 years after restoration to determine the restoration trajectory compared to a reference natural forest and two alternative land uses (arable field and agroforestry system) in the dry and wet seasons. Specifically, we investigated how land use and seasonality affected the activity density and species composition of spider communities. We also analysed whether individual spider species preferred certain land-use types or showed a strong seasonality, which might indicate their suitability as indicator species for restoration stages and success.

Methodology

Study site

The study was conducted in Ghana in the Ahafo region (Fig. 1), which is characterised by semi-deciduous forest (SDFZ), an average annual rainfall between 900 and 1,500 mm, and an average daily temperature of 25 °C. This region is characterised by two distinct seasons: the hot dry harmattan (November to March) and the rainy season (April to October) (Dampney et al. 2020). The Bosomkese Forest Reserve (agroforestry system; AS) is located in the semi-deciduous south eastern forest zone and is situated at 7°6.338'N, 2°14.782'W. The Asukese Forest Reserve (primary natural forest; NF) is located in the humid semi-deciduous north western forest zone at 7°8.469'N, 2°31.107'W.

The Terchire Restoration Area (restored forest; RF), which covers an area of 15.4 ha (2°10.842'N, 7°14.075'W), was exploited for gravel for road construction until 1998 and was actively restored in 1999 by planting indigenous and fast-growing exotic nitrogen-fixing tree seedlings (Dampney et al. 2020). The gravel site (GS) covers an area of approximately 4 ha and is located 1.8 km (7°14.150'N, 2°9.602'W) from the RF (Fig. 1). The GS has been abandoned since 1995 and is colonised by a few shrubby plants (*Chromolaena odorata* and *Pennisetum purpureum*). The arable field (AF) is located around the RF and is cultivated with maize, plantain, cassava and cocoa, among others (Dampney et al. 2020).

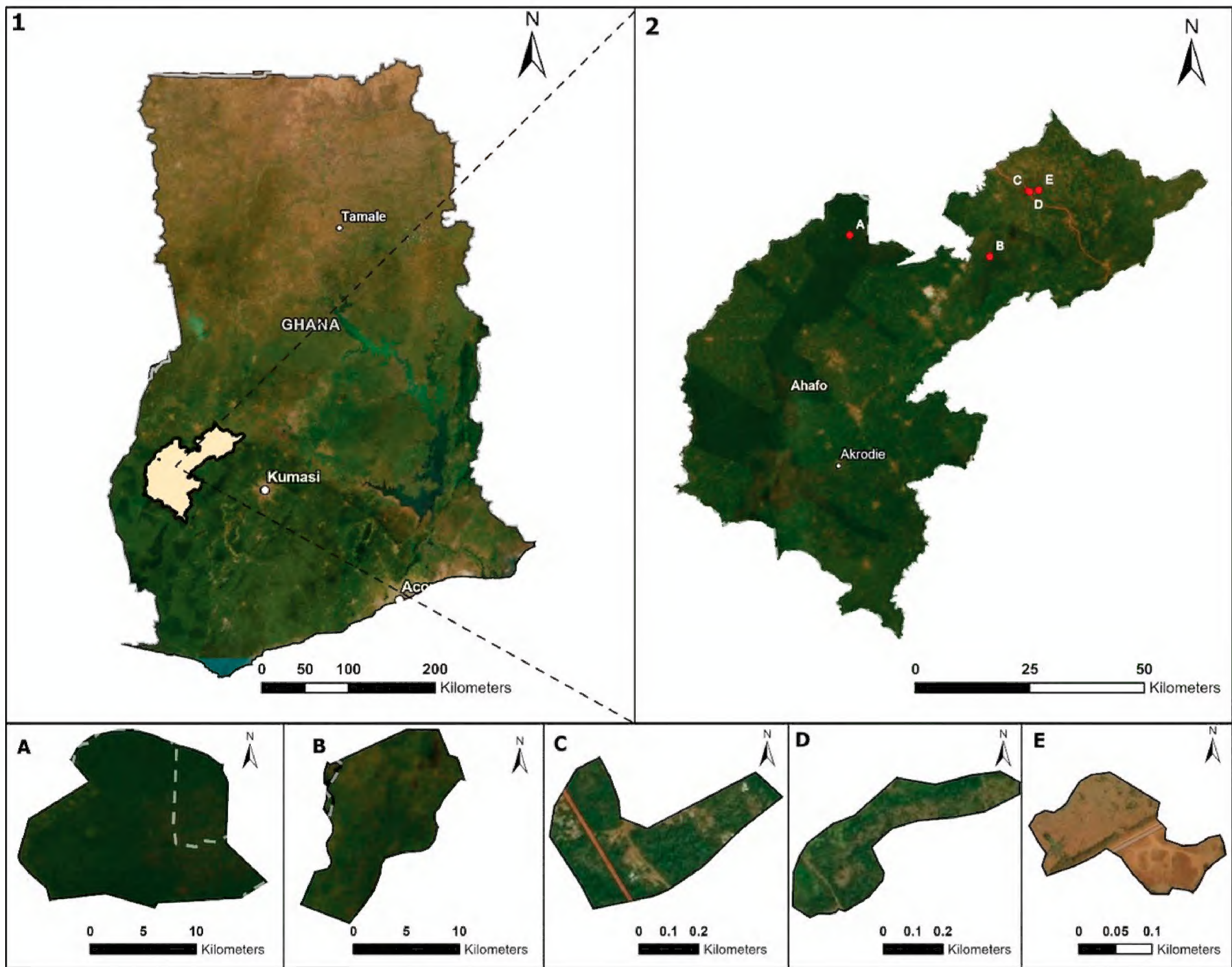


Figure 1. Map of Ghana (1) showing the Ahafo Region (2) and the studied land-use types (**A** Asukese Forest Reserve - Natural Forest - NF **B** Bosomkese Forest Reserve – Agroforestry System - AS **C** Restored Forest - RF **D** Arable Field -AF **E** Gravel Site-GS).

Sampling design

The five land-use types were studied in both seasons (dry and wet) using eight replicated 20 × 20 m plots, resulting in 40 study plots across the five land uses. Ground spider communities were sampled continuously, with five pitfall traps on each plot emptied weekly for 10 weeks in each sampling season. The first sampling campaign was conducted in the dry season (January to March 2019), followed by a rainy season campaign (June to August 2019). Pitfall traps were filled with a 50:50 mixture of ethylene glycol and water, and all pitfall traps were covered with small roofs to prevent the dilution of the trapping fluid by rain (Underwood and Quinn 2010). Pitfall trap samples were stored in 70% ethanol and later sorted into taxonomic groups (order, suborder or family) according to available identification keys for spiders (Dippenaar-Schoeman and Jocqué 1997).

Sample identification

In West Africa, most spider species have yet to be described, making it difficult to identify adults to species level due to the lack of taxonomic keys. To overcome this obstacle, the limited literature available (Roewer 1959; Henrard and

Jocqué 2017) was used to place some adults in the correct morphospecies. For others with insufficient or unavailable literature, further species identification was achieved through museum visits to the Royal Museum for Central Africa (RMCA), Tervuren, Belgium, and the Naturmuseum Senkenberg (SMF), Frankfurt, Germany. During these visits, complete identification of adult Ctenidae specimens to species level was achieved and many juveniles could be assigned to a specific genus. Most of the Lycosidae were identified as species by first examining the original taxonomic literature, followed by the examination of the original type specimens at the SMF (Roewer 1959). Only one species of Zodariidae could be identified to species level. The remaining six species (Appendix 2) were given provisional morphospecies codes as they represent undescribed species.

Data analysis

The overall activity density of spiders was based on the total catch of both juvenile and adult spiders in the families Ctenidae, Lycosidae and Zodariidae. The multivariate species composition of ground-hunting spider community focused only on the composition of identified species in these three families. The multivariate species composition of spider communities in different land uses and seasons, as well as the interaction term between land use and the season, was analysed using permutational multivariate analysis of variance (PERMANOVA) based on $\log(x+1)$ transformed activity densities of all species from the selected families and Bray-Curtis similarities (Clarke et al. 2014) and an unrestricted permutation of the raw data with 9999 permutations was applied (Anderson 2008). Land-use types (5 levels) and seasons (2 levels) were both used as fixed factors, and plots (8 levels) nested within the land-use types were used as random factors to reflect the repeated measures design. In case of statistically significant differences for a fixed factor, pairwise post-hoc tests were carried out for pairs of levels of factors and were performed using PERMANOVA. The same model was used to analyse the $\log(x+1)$ transformed overall activity density (the total number of ground-hunting spiders) and the inverse Simpson index based on Euclidean distances in each land use and for the three families. Non-metric multidimensional scaling (NMDS) ordination based on Bray-Curtis similarities was used to indicate the similarity between samples within and between plots of different land-use types and the goodness of fit of NMDS ordinations was assessed based on the 2-D stress value (Clarke et al. 2014). A similarity percentage analysis (SIMPER) was used to identify characteristic species for each land use and season, based Bray-Curtis similarities and a 70% cut-off for total contribution (Somerfield and Clarke 2013).

Results

A total of 1852 individual spiders from five land-use types (natural forest, agroforestry system, restored forest, arable field and gravel sites) and across two seasons (wet and dry) were identified in the three families. A total of 29 species, comprising 804 males, 397 females and 651 juveniles were identified from the following families: Ctenidae (7 species), Lycosidae (12) and Zodariidae (7) (Appendix 1).

Activity density and inverse Simpson index

The overall activity density of spiders differed significantly between land uses and seasons, and the interaction term between land uses and seasons was also significant (Table 1A). The overall activity density was highest in the restored forest followed by the natural forest (Fig. 2A). The overall activity density was higher in the dry season than in the wet season. The overall activity density of spiders was higher in the restored forest in both seasons and in the natural forest in the dry season than in the other land uses. The restored forest had the highest activity density in the dry season and the arable field had the lowest activity density in the wet season.

The inverse Simpson index differed significantly between land uses, but not between seasons and the interaction term between land uses and seasons was significant (Table 1B). The inverse Simpson index was highest on the gravel site in the wet season, followed by the gravel site in the dry season and the natural forest in both seasons (Fig. 2B). The inverse Simpson index was lowest in the arable field in both seasons and in the agroforestry system in the wet season.

Species composition across habitats and seasons

The species composition of spider communities differed between land-use types but not between seasons and the interaction term between land uses and season was also significant (Table 1C). The NMDS ordination shows dissimilarities between spider communities in the different land uses and followed a

Table 1. PERMANOVA results for the effect of the land use and season on the A) overall activity density, B) inverse Simpson index (Hill number 2) and C) multivariate species composition of spider communities (df: degree of freedom; SS: sum of squares, MS: mean sum of squares, Pseudo-F: F value by permutation, P(perm): P-values based on 9999. Significant effects are in bold.

A) Activity dens.	df	SS	MS	Pseudo-F	P(perm)
Plot	35	4257.90	121.65	1.64	0.072
Land use	4	6057.3	1514.3	12.448	0.001
Season	1	806.45	806.45	10.844	0.002
Land-use x Season	4	907.68	226.92	3.0513	0.031
Res	35	2602.9	74.368		
Total	79	14632			
B) Inv. Simpson	df	SS	MS	Pseudo-F	P(perm)
Plot	35	24.76	0.71	0.66	0.890
Land use	4	47.79	11.95	16.89	0.001
Season	1	0.24	0.24	0.22	0.639
Land-use x Season	4	12.50	3.12	2.91	0.037
Res	35	37.64	1.08		
Total	79	122.91			
C) Species comp.	df	SS	MS	Pseudo-F	P(perm)
Plot	35	50118.00	1431.90	1.35	0.016
Land use	4	78157.00	19539.00	13.65	0.001
Season	1	2235.60	2235.60	2.10	0.059
Land-use x Season	4	8211.40	2052.80	1.93	0.008
Res	35	37175.00	1062.10		
Total	79	175900.00			

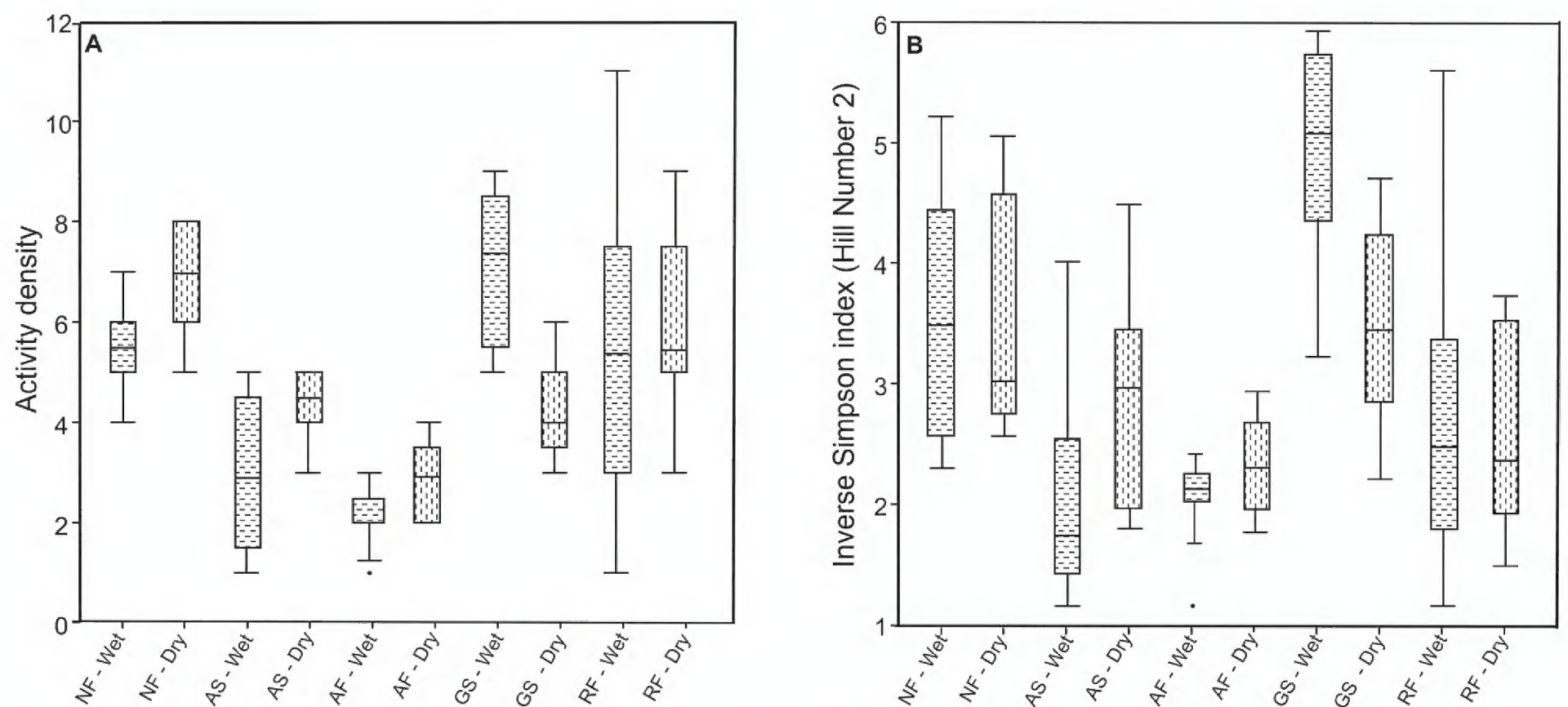


Figure 2. Overall activity density (**A**) and inverse Simpson index (**B**) (Hill number 2) of spiders for interactions between land-use types (NF, natural forest; AS, agroforestry system; AF, arable field; GS, gravel site; and RF, restored forest) and season (W, wet; D, dry). Single points indicate outliers based on the Median and Interquartile Deviation Method (IQD), the horizontal line is the median, boxes are 25th and 75th percentiles and whiskers show the 90th and 10th percentile respectively.

gradient from the gravel site through the arable field, agroforestry system and restored forest to the natural forest (Fig. 3). Spider communities in the agroforestry system overlapped with those in the restored forest.

Communities in the restored forest differed by 64% from the arable field with *Amicactenus eminens* (Arts, 1912), *Africactenus monitor* (Steyn & Jocqué, 2003), *Mallinella* sp3, and *Pardosa injucunda* (O. Pickard-Cambridge, 1876) having higher activity densities in the restored forest and with *Anahita lineata* (Simon, 1897) only present in the restored forest, but absent in the arable field. Furthermore, the communities in the restored forest differed by 68% from the gravel site with *Mallinella* sp3, *P. injucunda* and *Trochosa gentilis* (Roewer, 1960) having higher activity densities in the restored forest (Fig. 4). Similarly, *Hogna duala* (Roewer, 1959), *Hogna gratiosa* (Roewer, 1959), and *Mallinella bandamaensis* (Jézéquel, 1964) had higher activity densities in the gravel site, while *Mallinella* sp3 was only present in the restored forest but not in the gravel site.

Spider community composition differed by 68% between the restored forest and the gravel site, but the differences were mainly driven by the activity densities of the seven most common species. Higher activity densities of *Mallinella* sp3, *P. injucunda*, and *T. gentilis* were observed in the restored forest than in the gravel site while *M. bandamaensis*, *H. gratiosa*, *H. duala*, and *Hippasosa pilosa* (Alderweireldt, 1996) had higher activity densities at the gravel site. Communities in the reference natural forest differed by 61% from the restored forest with *A. eminens*, *A. monitor*, *Mallinella* sp1, *Mallinella* sp3 and having higher activity densities in the natural forest, and *A. lineata*, present only in the restored but not in the natural forest.

Species composition of spider communities only showed a statistical trend for differences between the wet and dry seasons and with the wet season characterised by higher activity densities of *H. duala*, *H. gratiosa*, *P. injucunda*, and *T. gentilis* (Fig. 5A–D).

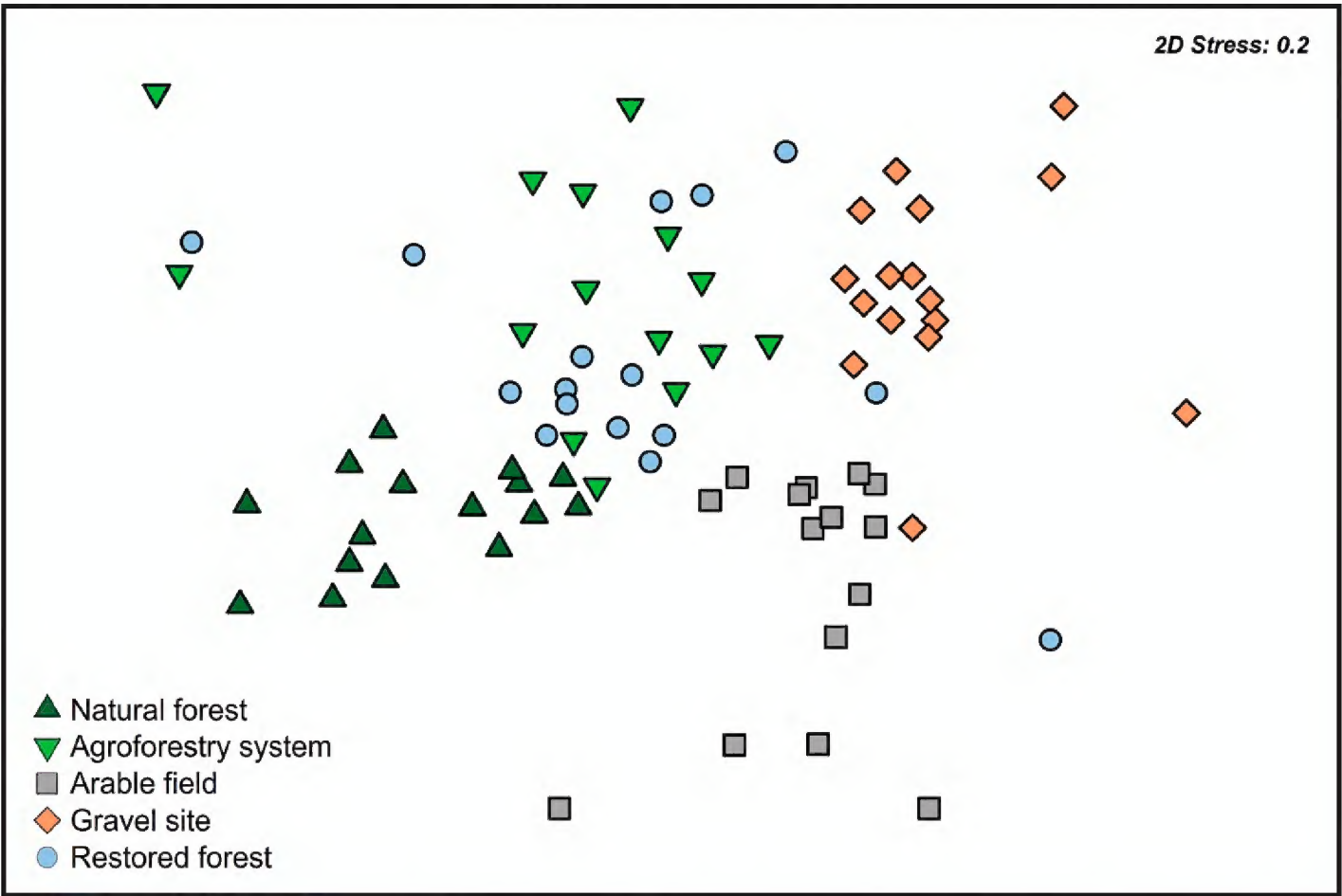


Figure 3. Non-metric multidimensional scaling (NMDS) ordination based on log-transformed ($\log(x+1)$) activity densities of spider species and Bray-Curtis similarities between plots of different land-use types. The 2-d stress value is 0.2.

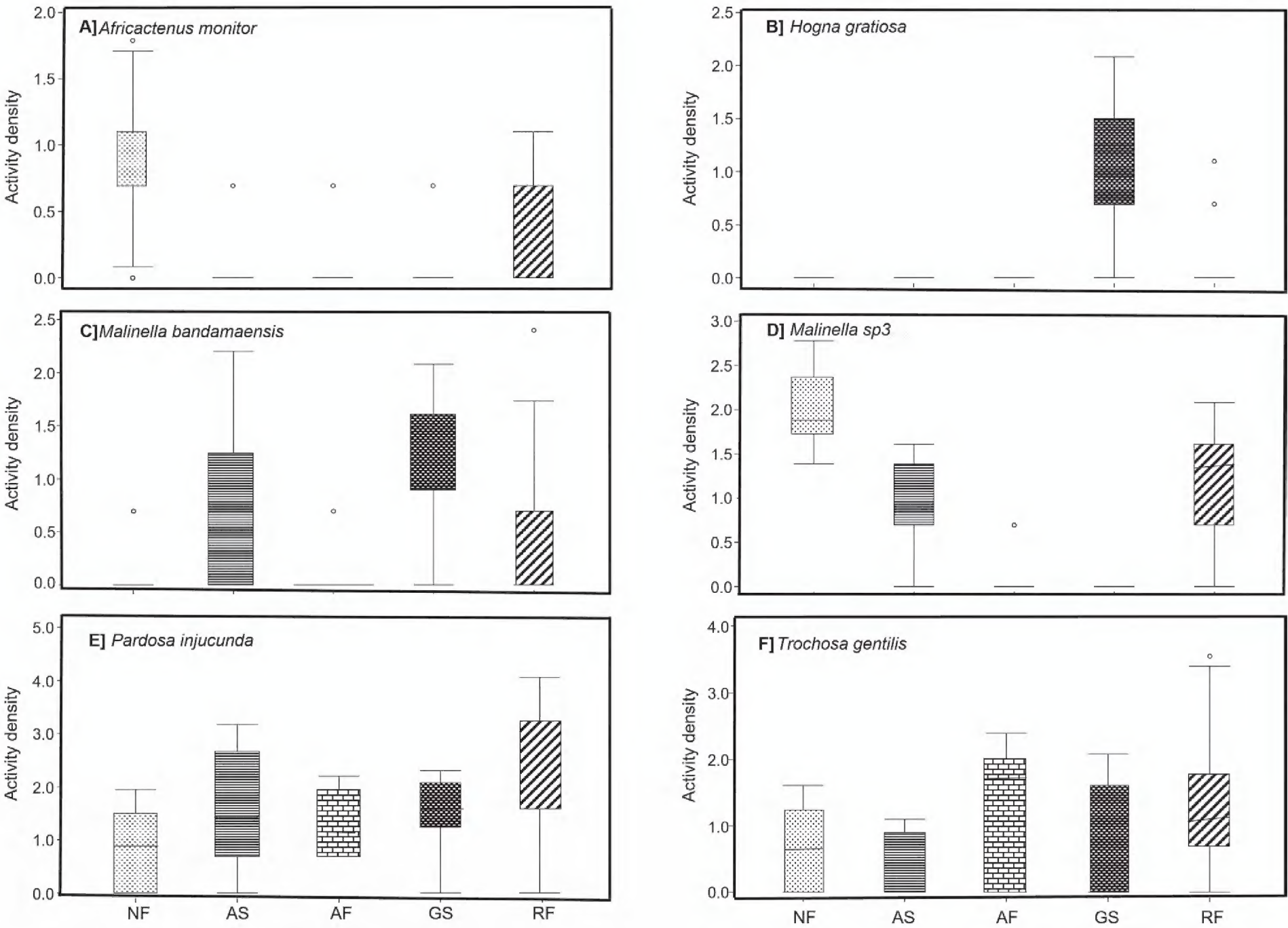


Figure 4. Box plots for activity densities of spider species across land-use types: NF, natural forest; AS, agroforestry system; AF, arable field; GS, gravel site; and RF, restored forest. Single points indicate outliers based on the Median and Interquartile Deviation Method (IQD), the horizontal line is the median, boxes are 25th and 75th percentiles and whiskers show the 90th and 10th percentile respectively.

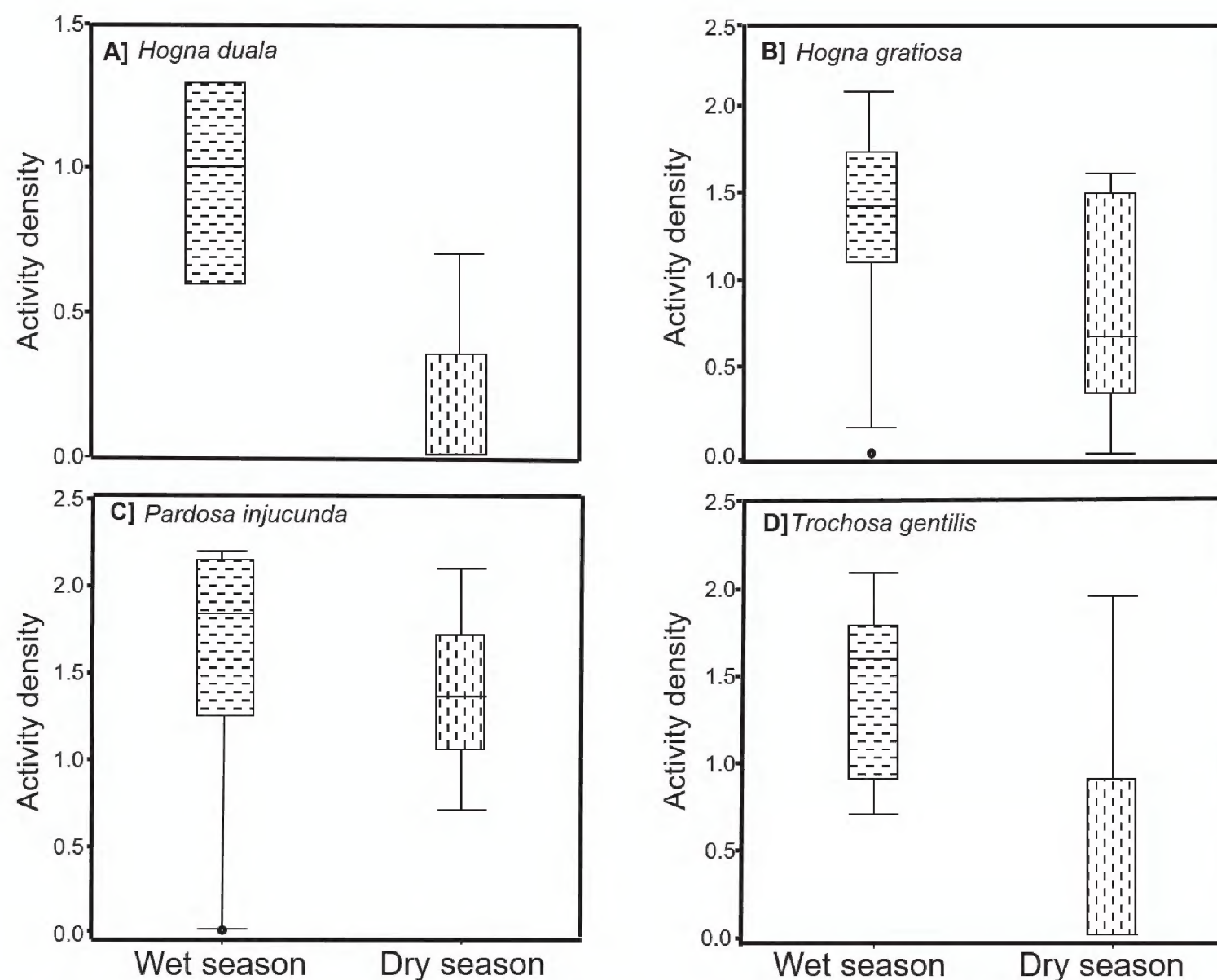


Figure 5. Box plots for activity densities of spider species across seasons (wet and dry). Single points indicate outliers based on the Median and Interquartile Deviation Method (IQD), the horizontal line is the median, boxes are 25th and 75th percentiles and whiskers show the 90th and 10th percentile respectively.

Discussion

Ground-hunting spider communities in the restored forest reached activity densities similar to the reference natural forest, but the diversity and species composition differed from the natural forest communities and were more similar to communities in the agroforestry system. Several environmental factors such as seasonality, habitat conditions, environmental stability, competition, predation (Ziesche and Roth 2008; Joseph et al. 2018; Juakaly and Jocqué 2021; La Flor et al. 2024) and other anthropogenic factors (e.g., forest encroachment: Foord et al. 2008) may have accounted for these differences in spider communities.

Activity density and inverse Simpson index

Natural and restored forests had higher activity densities than the unrestored gravel mine and the alternative land uses (arable field and agroforestry system). These forest systems have a more complex structure (Schirmel et al. 2016; Müller et al. 2022), more stable microclimate and environmental conditions (Müller et al. 2022), and higher prey availability (Menéndez-Acuña et al. 2023). The restored forest could be expected to support a more diverse spider community than the natural forest or the open ecosystems (arable fields and gravel mine) due to its dynamic nature in a transitional state. Typically, ecosystems in transition are characterised by unique habitat features (e.g., diverse tree communities, availability of deadwood, deep litter) and their stable environmental conditions (moderate temperature and relative humidity) (Schowalter 2017).

The results of this study are consistent with the findings of previous studies that observed higher spider activity densities as a result of restoration treatments that create complexity in vegetation structures, and provide more ecological niches and resources for spiders (Vymazalová et al. 2021; Dampney et al. 2023).

However, it is surprising to see a high inverse Simpson index of spiders in the gravel site where such habitat conditions are less diverse and low diversity in the restored forest. The inverse Simpson index is sensitive to changes in the most abundant species in a community (Keylock 2005), and a lower value in the restored forest compared to the gravel site indicates the dominance of very few spider species in the restored forest.

The observed differences in activity density between land uses depending on seasons illustrate how seasonal variations affect spider communities in the Afro-tropical region where seasonality is highly pronounced. Seasonal factors such as rainfall and temperature drive habitat conditions and subsequent temporal variation in species assemblages (Campuzano et al. 2020; Zapata et al. 2023). Seasonality is known to influence spider reproduction (e.g., rain favours egg hatching; Quijano-Cuervo et al. 2017), prey availability (e.g., high temperature reduces prey availability; Bidegaray-Batista et al. 2017), and habitat characteristics that influence spider mobility (Weeks and Holtzer 2000). Most spider species have a specific environmental preference, for which their activity is determined by the season that provides a microclimate within their physiological tolerance range (Sudhikumar et al. 2005). The higher activity density of spiders in the dry season than in the wet season could be related to the habitat structure created by the drier conditions, which increases the mobility of spiders and also makes them more susceptible to being captured by pitfall traps (Ahmed et al. 2023). The overall activity density of spiders in this study also considered both adult and juvenile spiders, so the higher activity density in the dry season is mainly due to juvenile spiders.

Species composition

Spider species composition in forests is largely determined by the diversity of tree species and the vegetation characteristics of habitats, which align with prey densities (Sudhikumar et al. 2005; Spears 2012). In essence, diverse communities provide more resources for spiders to thrive with complex vegetation structures providing additional niches and ecological refugia and protection from predation (Dampney et al. 2023). In a previous study in the same region, Dampney et al. (2023) described the vegetation of the gravel site as homogeneous and less diverse in terms of tree species compared to the heterogeneous and complex habitat structure of the restored and natural forest. It is important to note that only adult species from three families (Ctenidae, Lycosidae and Zodariidae) were considered for our study of community composition, in contrast to the analysis of overall activity density, which focused on both adult and juvenile spiders.

The gradient in community composition observed from the gravel site through the restored to the natural forest highlights the differences in spider communities between the land-use types. The natural forest had a unique spider community, probably driven by its habitat conditions characterised by old forest stands, deadwood and a diverse tree community (Dampney et al. 2023). *Mallinella* sp1, *Mallinella* sp3, and *A. monitor* characterised the natural forest community. *Mallinella* species are a commonly tropical forest-dwelling species

(Jocqué 1993; Dankittipakul et al. 2012) while the species *A. monitor* is a typical forest spider (Steyn et al. 2003; Jocqué et al. 2005; Henrard and Jocqué 2017).

The unique homogeneous habitat characteristic of the gravel site supported specialised species such as *Hogna gratiosa*, and *Mallinella bandamaensis* that are often found in open habitats. *Mallinella bandamaensis*, for example, prefers open degraded habitats and the species is well adapted to hunting prey in such habitats. The unique community of the arable field was dominated by *Pardosa injucunda* and *Trochosa gentilis* as additional species, showing preferences for open and disturbed environments (Liu et al. 2024). *Pardosa injucunda* is known to have high activity densities in open or low vegetation environments such as the arable fields (Liu et al. 2024). Similarly, the low overall activity density of spiders on arable field could be due to the use of pesticides or other agricultural practices such as tillage, which may have reduced spider numbers through direct mortality and indirectly reducing prey availability (Thorbek and Bilde 2004; Benamu 2020).

The restored forest had a spider community with a mix of species from the different land-use types. For example, *Mallinella* sp3, *Pardosa injucunda*, and *Trochosa gentilis*, which characterised the communities in the restored forest, were also observed in the natural forest, agroforestry system and the arable field. This reflects the development stage of the restored forest in terms of biodiversity mimicking spider communities from both the historical stage prior to restoration (gravel site) and the reference land-use types (natural forest).

Conclusion

Spider communities differed between land-use types depending on seasons, with activity densities, but not diversity or species composition, with the restored forest resembling the natural forest. The species composition of the communities in the restored forest was dissimilar to those in the gravel site and arable field, confirming the intermediate state between these land uses and natural forest. These results highlight the benefits of restoring former mining sites, but also the trade-offs in terms of restoration objectives, as natural forest biodiversity was not achieved after 20 years in restoration approaches that also aimed to provide direct benefits to local human communities (agroforestry system and actively restored forest). Nevertheless, it is clear from our results that restoration strategies are effective at increasing activity densities and certainly more effective from a conservation point of view than leaving degraded systems unmanaged and unable to self-recover.

Acknowledgement

We are grateful to Newmont Gold Ghana Limited and the Forest Service Division of Ghana for providing FGD permission to carry out this research. We appreciate the contribution of Daniel Kwame Debrah during the fieldwork. We also appreciate the assistance of Nadine Dupérré (Museum of Nature Hamburg – Zoology, Leibniz Institute for the Analysis of Biodiversity Change (LIB) Hamburg) for assisting with identification of spiders to family and Peter Jaeger (Senckenberg Natural History Museum, Frankfurt) in facilitating the examination of type specimens during identification. We are also grateful to the Rufford Foundation for funding HK's (39660-1) field campaign in Ghana.

Additional information

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical statement

The non-invasive sampling methods did not harm or endanger trees and other animals.

Funding

We declare that no financial support was received from Newmont Gold Ghana Limited.

Author contributions

Harriet Kinga: Conceptualization, methodology, investigation, taxonomy, data curation, formal analysis, writing. Frederick Gyasi Damphey: Conceptualization, methodology, investigation, formal analysis, writing. Danilo Harms: Conceptualization, taxonomy, formal analysis, writing. Arnaud Henrard: Taxonomy, writing. Rudy Jocqué: Taxonomy, writing. Klaus Birkhofer: Conceptualization, methodology, formal analysis, writing.

Author ORCIDs

Harriet Kinga  <https://orcid.org/0000-0002-3898-4274>

Frederick Gyasi Damphey  <https://orcid.org/0000-0001-5732-8814>

Danilo Harms  <https://orcid.org/0009-0006-7437-6897>

Rudy Jocqué  <https://orcid.org/0000-0003-1776-0121>

Arnaud Henrard  <https://orcid.org/0000-0003-3270-7193>

Data availability

All of the data that support the findings of this study are available in the main text.

References

- Abugre S, Sackey EK (2022) Diagnosis of perception of drivers of deforestation using the partial least squares path modeling approach. *Trees, Forests and People* 8: 100246. <https://doi.org/10.1016/j.tfp.2022.100246>
- Ahmed DA, Beidas A, Petrovskii SV, Bailey JD, Bonsall MB, Hood AS, Haase P (2023) Simulating capture efficiency of pitfall traps based on sampling strategy and the movement of ground-dwelling arthropods. *Methods in Ecology and Evolution* 14(11): 2827–2843. <https://doi.org/10.1111/2041-210X.14174>
- Anderson MJ (2008) PERMANOVA+ for PRIMER: guide to software and statistical methods. *PRIMER-E*: 214.
- Asare D, Ansong M, Kyereh B, Damphey FG, Asante WA (2022) Mining methods exert differential effects on species recruitment at artisanal small-scale mining sites in Ghana. *Heliyon* 8(5): e09434. <https://doi.org/10.1016/j.heliyon.2022.e09434>
- Benamu MA (2020) The importance of spider diversity in agroecosystems and the effect of pesticides. *Global Journal of Ecology* 5: 60–61. <https://doi.org/10.17352/gje.000023>
- Bentsi-Enchill F, Damphey FG, Pappoe ANM, Ekumah B, Akotoye HK (2022) Impact of anthropogenic disturbance on tree species diversity, vegetation structure and carbon storage potential in an upland evergreen forest of Ghana, West Africa. *Trees, Forests and People* 8: 100238. <https://doi.org/10.1016/j.tfp.2022.100238>

- Bidegaray-Batista L, Arnedo M, Carlozzi A, Jorge C, Plischoff P, Postiglioni R, et al. (2017) Dispersal strategies, genetic diversity, and distribution of two wolf spiders (Araneae, Lycosidae): potential bio-indicators of ecosystem health of coastal dune habitats of South America. *Behaviour and ecology of spiders: Contributions from the neotropical region*, 109–135. https://doi.org/10.1007/978-3-319-65717-2_5
- Birkhofer K, Bezemer TM, Hedlund K, Setälä H (2012) Community composition of soil organisms under different wheat farming systems. *Microbial ecology in sustainable agroecosystems*, 89–111. <https://doi.org/10.1201/b12339-6>
- Birkhofer K, Buxton M, Feng L, Simba L, Diekötter T (2024) Conserving insects for the provision of ecosystem services. *Routledge Handbook of Insect Conservation*, 53–62. <https://doi.org/10.4324/9781003285793-6>
- Brown HCA, Appiah M, Quansah GW, Adjei EO, Berninger F (2024) Soil carbon and bio-physicochemical properties dynamics under forest restoration sites in southern Ghana. *Geoderma Regional* 38: e00838. <https://doi.org/10.1016/j.geodrs.2024.e00838>
- Bullock JM, Aronson J, Newton AC, Pywell RF, Rey-Benayas JM (2011) Restoration of ecosystem services and biodiversity: Conflicts and opportunities. *Trends in Ecology & Evolution* 26(10): 541–549. <https://doi.org/10.1016/j.tree.2011.06.011>
- Campuzano EF, Ibarra-Núñez G, Machkour-M´ Rabet S, Morón-Ríos A, Jiménez ML (2020) Diversity and seasonal variation of ground and understory spiders from a tropical mountain cloud forest. *Insect Science* 27(4): 826–844. <https://doi.org/10.1111/1744-7917.12693>
- Cardoso P, Pekar S, Birkhofer K, Chuang A, Fukushima CS, Hebets EA, Mammola S (2024) Ecosystem services provided by spiders. *Authorea Preprints*. <https://doi.org/10.22541/au.172538631.11011603/v1>
- Clarke KR, Gorley RN, Somerfield PJ, Warwick RM (2014) *Change in marine communities: an approach to statistical analysis and interpretation*. 3rd edn., PRIMER-E, Plymouth.
- Dankittipakul P, Jocque R, Singtripop T (2012) Systematics and biogeography of the spider genus *Mallinella* Strand, 1906, with descriptions of new species and new genera from Southeast Asia (Araneae, Zodariidae). *Zootaxa* 3369(1): 1–327. <https://doi.org/10.11646/zootaxa.3369.1.1>
- Dampney FG, Birkhofer K, Nsiah PK, de la Riva EG (2020) Soil properties and biomass attributes in a former gravel mine area after two decades of forest restoration. *Land* 9(6): 209. <https://doi.org/10.3390/land9060209>
- Dampney FG, de la Riva EG, Birkhofer K (2021) Trade-offs and synergies between food and fodder production and other ecosystem services in an actively restored forest, natural forest and an agroforestry system in Ghana. *Frontiers in Forests and Global Change* 4: 630959. <https://doi.org/10.3389/ffgc.2021.630959>
- Dampney FG, Djoudi EA, Birkhofer K (2023) Effects of post-mining forest restoration and alternative land uses on ground-dwelling arthropods in Ghana. *Community Ecology* 24(2): 215–228. <https://doi.org/10.1007/s42974-023-00144-8>
- Dippenaar-Schoeman AS, Jocqué R (1997) *African spiders: an identification manual*. Pretoria: ARC-Plant Protection Research Institute.
- Dippenaar-Schoeman AS, Van den Berg AM, Van den Berg MA, Foord SH (2005) Spiders in avocado orchards in the Mpumalanga Lowveld of South Africa: species diversity and abundance (Arachnida: Araneae). *African Plant Protection* 11: 8–16.
- FAO and UNEP (2020) *The State of the World's Forests 2020*. The State of the World's Forests 2020. <https://doi.org/10.4060/ca8642en>
- Fitzgerald M, Nackoney J, Potapov P, Turubanova S (2021) Agriculture is the primary driver of tree cover loss across the Forestière region of the Republic of Guin-

- ea, Africa. Environmental Research Communications 3(12): 121004. <https://doi.org/10.1088/2515-7620/ac4278>
- Foord SH, Mafadza MM, Dippenaar-Schoeman AS, Van Rensburg BJ (2008) Micro-scale heterogeneity of spiders (Arachnida: Araneae) in the Soutpansberg, South Africa: a comparative survey and inventory in representative habitats. African Zoology 43(2): 156–174. <https://doi.org/10.3377/1562-7020-43.2.156>
- Foord SH, Dippenaar-Schoeman AS, Haddad CR, Lyle R, Lotz LN, Sethusa T, Raimondo D (2020) The South African National Red List of spiders: Patterns, threats, and conservation. The Journal of Arachnology 48(2): 110–118. <https://doi.org/10.1636/0161-8202-48.2.110>
- Frenzel T, Rischen T, Fischer K (2022) Humid grassland fallows promote spider diversity in a traditionally managed landscape. Basic and Applied Ecology 63: 59–70. <https://doi.org/10.1016/j.baae.2022.05.007>
- Hansen MC, Stehman SV, Potapov PV (2010) Quantification of global gross forest cover loss. Proceedings of the National Academy of Sciences of the United States of America 107(19): 8650–8655. <https://doi.org/10.1073/pnas.0912668107>
- Henrard A, Jocqué R (2017) Morphological and molecular evidence for new genera in the Afrotropical Cteninae (Araneae, Ctenidae) complex. Zoological Journal of the Linnean Society 180: 82–154. <https://doi.org/10.1111/zoj.12461>
- Jocqué R (1993) We'll meet again, an expression remarkably applicable to the historical biogeography of Australian Zodariidae. Memoirs of the Queensland Museum 33: 561–564.
- Jocqué R, Alderweireldt M (2006) Lycosidae: The grassland spiders. Acta Zoologica Bulgarica (Suppl. 1): 125–130.
- Jocqué R, Samu F, Bird T (2005) Density of spiders (Araneae: Ctenidae) in Ivory Coast rainforests. Journal of Zoology 266(1): 105–110. <https://doi.org/10.1017/S0952836905006746>
- Joseph GS, Mauda EV, Seymour CL, Munyai TC, Dippenaar-Schoeman A, Foord SH (2018) Landuse change in savannas disproportionately reduces functional diversity of invertebrate predators at the highest trophic levels: Spiders as an example. Ecosystems 21(5): 930–942. <https://doi.org/10.1007/s10021-017-0194-0>
- Juakaly MJL, Jocqué R (2021) Resilience of epigeal spiders (Araneae) after clear-felling for agriculture in a Central African rainforest. Arachnology 18(8): 849–858. <https://doi.org/10.13156/arac.2021.18.8.849>
- La Flor YA, Perry KI, Collis LM, Phelan PL, Gardiner MM (2024) Biotic and abiotic factors drive multi-trophic interactions among spiders at different spatial scales in urban green-spaces. Journal of Urban Ecology 10: juae008. <https://doi.org/10.1093/jue/juae008>
- Keylock C (2005) Simpson diversity and the Shannon–Wiener index as special cases of a generalized entropy. Oikos 109(1): 203–207. <https://doi.org/10.1111/j.0030-1299.2005.13735.x>
- Kumi S, Nsiah PK, Ahiabu HK, Sackey E (2024) Barriers and opportunities in effective management of forest landscape restoration: Tain II degraded forest restoration, Ghana. Trees, Forests and People 15: 100483. <https://doi.org/10.1016/j.tfp.2023.100483>
- Kyerematen R, Adu-Acheampong S, Acquah-Lamptey D, Anderson RS (2020) Using Orthoptera and Hymenoptera indicator groups as evidence of degradation in a mining concession (Tarkwa gold mine) in Ghana. International Journal of Tropical Insect Science 40(1): 221–224. <https://doi.org/10.1007/s42690-019-00053-2>
- Liu L, Fu D, Luo Y (2024) Grassland expansions promoted global diversification of the *Pardosa* wolf spiders during the late Cenozoic (Araneae, Lycosidae). Zoosystematics and Evolution 100(4): 1287–1296. <https://doi.org/10.3897/zse.100.128885>

- Marc P, Canard A, Ysnel F (1999) Spiders (Araneae) useful for pest limitation and bio-indication. *Agriculture, Ecosystems & Environment* 74(1–3): 229–273. [https://doi.org/10.1016/S0167-8809\(99\)00038-9](https://doi.org/10.1016/S0167-8809(99)00038-9)
- Masolele RN, Marcos D, De Sy V, Abu IO, Verbesselt J, Reiche J, Herold M (2024) Mapping the diversity of land uses following deforestation across Africa. *Scientific Reports* 14(1): 1681. <https://doi.org/10.1038/s41598-024-52138-9>
- Menéndez-Acuña M, Salas-Rodríguez M, Montiel-Parra G, Sotuyo S, Rosas-Echeverría MV (2023) Seasonality and Long-Term Effect of Environmental Variables on the Orb Weaver Spider Community of a Tropical Dry Forest in the Balsas Basin, Mexico. *Diversity* 15(3): 466. <https://doi.org/10.3390/d15030466>
- Müller J, Brandl R, Cadotte MW, Heibl C, Bässler C, Weiß I, Seibold S (2022) A replicated study on the response of spider assemblages to regional and local processes. *Ecological Monographs* 92(3): e1511. <https://doi.org/10.1002/ecm.1511>
- Nero BF (2021) Structure, composition and diversity of restored forest ecosystems on mine-spoils in South-Western Ghana. *PLoS ONE* 16(6): e0252371. <https://doi.org/10.1371/journal.pone.0252371>
- Nyffeler M, Birkhofer K (2017) An estimated 400–800 million tons of prey are annually killed by the global spider community. *Naturwissenschaften* 104(3–4): 1–12. <https://doi.org/10.1007/s00114-017-1440-1>
- Nzigidahera B, Desnyder W, Jocqué R (2011) An overview of the Afrotropical species of *Mallinella* (Araneae, Zodariidae) with the description of a remarkable new species from Burundi. *Journal of Afrotropical Zoology* 7: 19–27.
- Ong SQ, Hamid SA (2022) Next generation insect taxonomic classification by comparing different deep learning algorithms. *PLoS ONE* 17(12): e0279094. <https://doi.org/10.1371/journal.pone.0279094>
- Potapov AM, Beaulieu F, Birkhofer K, Bluhm SL, Degtyarev MI, Devetter M, Scheu S (2022) Feeding habits and multifunctional classification of soil-associated consumers from protists to vertebrates. *Biological Reviews of the Cambridge Philosophical Society* 97(3): 1057–1117. <https://doi.org/10.1111/brv.12832>
- Quijano Cuervo L, Martínez-Hernández N, Sabogal-González A (2017) Temporal variation of the abundance and some population aspects of *Micrathena* species (Araneae: Araneidae) in a Dry Tropical Forest (DTF) from Colombian Caribbean. *Ecología Austral* 27(02): 99–311. <https://doi.org/10.25260/EA.17.27.2.0.112>
- Ritchie H, Spooner F, Roser M (2021) Forests and Deforestation. *OurWorldinData.org*. <https://ourworldindata.org/forests-and-deforestation> [Online Resource]
- Roewer CF (1959) Araneae Lycosaeformia II (Lycosidae)(Fortsetzung und Schluss). *Explor. Parc natn. Upemba Miss.* 55: 519–1040.
- Schirmel J, Thiele J, Entling MH, Buchholz S (2016) Trait composition and functional diversity of spiders and carabids in linear landscape elements. *Agriculture, Ecosystems & Environment* 235: 318–328. <https://doi.org/10.1016/j.agee.2016.10.028>
- Schowalter T (2017) Arthropod diversity and functional importance in old-growth forests of North America. *Forests* 8(4): 97. <https://doi.org/10.3390/f8040097>
- Somerfield PJ, Clarke KR (2013) Inverse analysis in non-parametric multivariate analyses: Distinguishing groups of associated species which covary coherently across samples. *Journal of Experimental Marine Biology and Ecology* 449: 261–273. <https://doi.org/10.1016/j.jembe.2013.10.002>
- Spears L (2012) Spider community composition and structure in a shrub-steppe ecosystem: the effects of prey availability and shrub architecture. *All Graduate Theses and Dissertations*, 1207. <https://doi.org/10.26076/f608-744f>

- Steyn TL, Van der Donckt JF, Jocqué R (2003) The Ctenidae (Araneae) of the rainforests in eastern Côte d'Ivoire. *Annls. Mus. R. Afr. centr. (Zool.)* 290: 129–166.
- Sudhikumar AV, Mathew MJ, Sunish E, Murugesan S, Sebastian PA (2005) Preliminary studies on the spider fauna in Mannavan shola forest, Kerala, India (Araneae). *European Arachnology (Supplement 1)*: 319–327.
- Thorbek P, Bilde T (2004) Reduced numbers of generalist arthropod predators after crop management. *Journal of Applied Ecology* 41(3): 526–538. <https://doi.org/10.1111/j.0021-8901.2004.00913.x>
- Underwood EC, Quinn JF (2010) Response of ants and spiders to prescribed fire in oak woodlands of California. *Journal of Insect Conservation* 14(4): 359–366. <https://doi.org/10.1007/s10841-010-9265-7>
- Vymazalová P, Košulič O, Hamřík T, Šipoš J, Hédli R (2021) Positive impact of traditional coppicing restoration on biodiversity of ground-dwelling spiders in a protected lowland forest. *Forest Ecology and Management* 490: 119084. <https://doi.org/10.1016/j.foreco.2021.119084>
- Weeks Jr RD, Holtzer TO (2000) Habitat and season in structuring ground-dwelling spider (Araneae) communities in a shortgrass steppe ecosystem. *Environmental Entomology* 29(6): 1164–1172. <https://doi.org/10.1603/0046-225X-29.6.1164>
- World Bank Group (2020) Annual Report 2020: Angola, Nigeria, and South Africa. World Bank Group, Washington, DC, 2020. www.worldbank.org
- Zapata W, Vergara-Moreno D, Carrillo-Pallares M, Segovia-Paccini A, Navas SGR, Malumbres-Olarte J (2023) Seasonal diversity of spider assemblages (Araneae: Arachnida) in the “Guillermo Piñeres” Botanical Garden, Turbaco–Colombia. *Neotropical Biodiversity* 9(1): 17–28. <https://doi.org/10.1080/23766808.2022.2157948>
- Ziesche TM, Roth M (2008) Influence of environmental parameters on small-scale distribution of soil-dwelling spiders in forests: What makes the difference, tree species or microhabitat? *Forest Ecology and Management* 255(3–4): 738–752. <https://doi.org/10.1016/j.foreco.2007.09.060>

Appendix 1

Table A1. Number of identified spider species on various habitat.

Family	Species	Agroforestry	Arable Field	Gravel Site	Natural Forest	Restored Forest	Total
Ctenidae	<i>Africactenus monitor</i> Steyn & Jocqué, 2003	1	1	1	24	8	35
	<i>Africactenus</i> sp.	1	1		8		10
	<i>Amicactenus eminens</i> Arts, 1912		2		13	9	24
	<i>Amicactenus fallax</i> Steyn & Van der Donckt, 2003				4		4
	<i>Amicactenus</i> sp.	10		2	13	12	37
	<i>Anahita aculeata</i> Simon, 1897			1		2	3
	<i>Anahita lineata</i> Simon, 1897	6		1		16	23
	<i>Anahita</i> sp.	6	2	3	26	15	52
	<i>Petaloctenus bossema</i> Jocqué & Steyn, 1997				3		3
	<i>Petaloctenus</i> sp.	2			12	2	16
	<i>Piloctenus mirificus</i> Arts, 1912				1	1	2
Lycosidae	<i>Alopecosa</i> sp.n		6	1		2	9
	<i>Geolycosa</i> sp.n			1			1
	<i>Hippasa albopunctata</i> Thorell, 1899			5		1	6
	<i>Hippasa lamtoensis</i> Dresco, 1981					1	1
	<i>Hippasa</i> sp.			2			2
	<i>Hippasa brechti</i> Alderweireldt & Jocqué, 2005			4		1	5
	<i>Hippasosa pilosa</i> Roewer, 1960			14	1	2	17
	<i>Hippasosa</i> sp.	1	2	25		6	34
	<i>Hogna duala</i> Roewer, 1959		2	18	1	12	33
	<i>Hogna gratiosa</i> Roewer, 1959			41		4	45
	<i>Hogna simoni</i> Roewer, 1959			2		6	8
	<i>Hogna</i> sp.		4	13	4	5	26
	<i>Pardosa injucunda</i> O. Pickard-Cambridge, 1876	106	56	71	32	253	518
	<i>Pardosa</i> sp.	25	23	48	55	38	189
	<i>Trochosa gentilis</i> Roewer, 1960	11	67	38	22	74	212
	<i>Trochosa mundamea</i> Roewer, 1960			2		3	5
	<i>Trochosa</i> sp.	3	13	27	6	17	66
Zodariidae	<i>Dusmadiores</i> sp.n					1	1
	<i>Mallinella bandamaensis</i> Jézéquel, 1964	27	1	48	3	15	94
	<i>Mallinella</i> sp.	11	2	12	21	18	64
	<i>Mallinella</i> sp1	2	1	1	40	1	45
	<i>Mallinella</i> sp2	2		4	4	2	12
	<i>Mallinella</i> sp3	30	2		148	45	225
	<i>Mallinella</i> sp4				4		4
	<i>Mallinella</i> sp5	8	2	1	5	5	21

Appendix 2



Figure A1. Pictures of some spiders observed during the study **A** *Amicactenus eminens* (Arts, 1912), Ctenidae **B** *Piloctenus mirificus* (Arts, 1912) **C** *Hippasa* sp., Lycosidae **D** *Mallinella bandamaensis* (Jézéquel, 1964). Photos by Arnaud Henrard.